August 2001 • NREL/CP-500-30586

Conference Paper

Preparing an Existing Diesel Power Plant for a Wind Hybrid Retrofit: Lessons Learned in the Wales, Alaska, Wind-Diesel Hybrid Power Project

Stephen Drouilhet
National Renewable Energy Laboratory

Presented at the WINDPOWER 2001 Conference
Washington, D.C.
June 4 – June 6, 2001

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

Available electronically at http://www.doe.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Preparing an Existing Diesel Power Plant for a Wind Hybrid Retrofit: Lessons Learned in the Wales, Alaska, Wind-Diesel Hybrid Power Project

Stephen Drouilhet, P.E.
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO, 80401 USA

1 Introduction

In countries around the world, there are many communities not served by national or regional electric grids. In many of these communities, power is generated by small diesel power plants that range in size from about 100 kW to several MW. There are thousands, perhaps tens of thousands, of isolated diesel-powered villages worldwide. In the state of Alaska alone, there are approximately 200 diesel-powered communities. In addition to village power systems, there are hundreds or thousands of diesel plants providing power to a variety of remote commercial and industrial facilities, including mining operations, military bases, resorts, and fish farming and processing operations.

There are many reasons why diesel power systems are so widespread. Diesel generators are by far the lowest capital cost electric generation technology in the sub-MW size range. They are a well-established and well-understood technology and there is a worldwide support infrastructure in place. When properly operated and maintained they are also very robust and reliable. However, diesels also have major disadvantages. They are noisy and emit significant air pollution. Though relatively cheap on the world market, transportation costs can make diesel fuel very expensive in remote locations. In arctic communities, where fuel may only be delivered once per year, fuel storage costs also are very high, and the risks of major fuel spills greater. Finally, because diesels require frequent oil changes and other service at regular intervals, they have a relatively high maintenance cost per kWh delivered.

Wind-diesel hybrid power systems preserve the advantages of diesel generators while mitigating their disadvantages. Wind turbines have a higher cost per installed kW capacity, but zero emissions, zero fuel cost, and lower routine maintenance requirements than diesels. Rural utilities and national energy agencies worldwide are beginning to see the opportunity that wind-diesel hybrids offer to reduce the life-cycle cost and environmental impact of rural electric service. Because an existing diesel plant frequently represents a substantial investment, it often appears more cost-effective to retrofit wind turbines, system controls, and any other required ancillary components to the existing power system rather than build a completely new wind-diesel hybrid system from the ground up. This was true in the case of the Wales, Alaska, High-Penetration Wind-Diesel Project, a technology demonstration project in which the National Renewable Energy Laboratory (NREL) collaborated with the Kotzebue Electric Association (KEA), the Alaska Village Electric Cooperative (AVEC), and the Alaska Energy Authority (AEA).

Most of the engineering effort on the Wales project focused on the design and development of the new system components, primarily the main system controller and the energy storage subsystem. Comparatively little attention was paid to the diesel plant itself and to the modifications necessary to successfully integrate it into a fully automated wind-diesel hybrid system. Consequently, many diesel plant shortcomings were overlooked until they manifested themselves in the field during the start-up and commissioning of the wind-diesel hybrid system. The resulting problems revealed that in such a system, the diesel plant must perform to a higher standard of performance than is often expected of the typical village power plant, which is usually designed to be completely manually operated. These higher performance requirements necessitate more rigorously designed diesel plants. Design shortcomings were found in all of the major diesel plant subsystems (engine cooling and fuel systems, generators, controls, switchgear, and distribution system). These shortcomings primarily affected the following areas: ease of retrofit system installation, frequency and voltage stability, time for diesel start-up and synchronization, generator paralleling, load-sharing stability, and plant and engine temperature control. This paper discusses each of the relevant plant design considerations in detail, in hopes that by sharing this experience, system integrators and project planners will give proper attention to diesel plant preparation (or replacement), and future wind-diesel systems will be installed and commissioned more quickly and cost-effectively.

2 Overview of the Wales, Alaska, High-Penetration Wind-Diesel Project

The configuration of the Wales wind-diesel system is shown in Figure 1. The system is composed of the existing diesel power plant, two 65-kW wind turbines, an AC/DC rotary power converter, a battery bank, two electric boilers serving as secondary loads, and a Programmable Logic Controller (PLC)-based main system controller.

Wind penetration is a term referring to the ratio of the wind power output to the village electric demand. According to the classification scheme used at NREL's National Wind Technology Center, a high-penetration wind-diesel system is one in which the annual wind energy output of the wind turbines is at least 50% of the annual primary electric demand and in which the system has the capability to provide electric power with no diesels running during periods of sufficient wind power availability. The Wales wind-diesel system is thus a high-penetration system, because the Wales wind turbines are projected to generate approximately the same amount of energy annually as is consumed by the primary village load, and because the power system can operate diesel-off as long as the short-term average wind power exceeds the average load by a small margin.

The individual components of the wind-diesel system and their role in its operation are discussed in detail below.

2.1 Diesel Power Plant

The pre-existing diesel plant in Wales consists of two Cummins LTA10 and one Allis-Chalmers 3500 diesel gensets, rated as shown in Figure 1. Prior to the implementation of the wind-diesel system, the plant was entirely manually controlled, with the operator deciding when to run the various generators and manually starting, stopping, and synchronizing them to the grid. The gensets are of different ages and origins and, prior to this project, were equipped with various assorted voltage regulators, governors, and actuators.

Manual diesel operation is incompatible with the effective implementation of a high-penetration wind-diesel system. Maximum fuel savings demands that only the most efficient diesel(s) adequate to meet the net load (village load minus available wind power) are run at all times. Furthermore, to capture the additional fuel and maintenance savings made possible by a reduction in diesel run time, the diesels must be shut down completely when there is more than enough wind power to meet the load. Under such an operating regime, the starting and stopping of any particular genset will be more frequent and unpredictable than is feasible with a manually controlled system. For this reason, the first step in system installation was to retrofit all diesels with controls making them capable of automatic starting, stopping, synchronization, and load-sharing.

2.2 Wind Turbines

The project has installed two 65-kW wind turbines manufactured by Atlantic Orient Corporation, each of which has a 3-bladed downwind stall-regulated rotor and an induction generator. Because the turbines use induction generators, they rely on excitation from the line to generate power. Lacking any inherent control over voltage or frequency, induction machines generate power at whatever voltage and frequency exists on the line to which they are connected. Voltage and frequency must be controlled elsewhere in the system. Even when generating positive power, the generators draw reactive power (VARs) from the line. This reactive power must be supplied by other components in the system, either by the diesel generators or by the AC machine of the rotary converter, as described later.

2.3 Energy Storage

As discussed above, the main performance objective for the wind-diesel system is to minimize fuel consumption. This can be done by ensuring that only the smallest adequate diesel is run at any given time and that all diesels are off as much of the time as possible. Several researchers have shown that by providing a small amount of energy storage, unnecessary diesel starts (those that occur even when the average wind power plus the diesel capacity already on-line is adequate to meet the average load) can be greatly reduced, with a significant impact both on fuel savings and on total diesel run time. The optimal amount of storage depends on a variety of factors, including the number of wind turbines (a larger number of turbines will give a greater wind power smoothing effect), the variability of the wind, the variability of the village load, the cost of fuel, and the cost of storage. The Wales system is equipped with a battery bank sized to provide enough energy storage to meet about two thirds of the average village load for about 15 minutes.

2.4 Rotary Power Converter

The rotary converter serves two purposes in the operation of the power system. It is the interface between the 480 VAC bus and the battery bank. It also supplies some or all of the reactive power demanded by the load and by the wind turbine generators. The converter consists of an AC synchronous generator shaft coupled to a DC motor. In its dual role, the AC machine acts sometimes as a motor/generator, sometimes only as a synchronous condenser. The field excitation on the AC machine is controlled by a standard generator voltage regulator. The field of the DC machine is controlled by the main system controller.

Whenever one or more diesel gensets is operating, the system voltage and frequency is maintained by the gensets' voltage regulator and governor. When no diesels are operating, both frequency and voltage must be regulated by the rotary converter. The system voltage is controlled by the AC machine's voltage regulator, and the frequency is maintained by controlling the DC machine field current, thereby modulating the power flow to or from the battery bank. In effect, system voltage is regulated by maintaining a reactive power balance on the system, and frequency is regulated by maintaining a real power balance.

2.5 Secondary Loads

In any high-penetration wind-diesel system, there are times when the wind turbine power output exceeds the load. To maintain system stability, this excess power must be dissipated. As discussed above, to the extent that the battery bank can accept it, excess power will be absorbed by the battery. However, when the battery is full or when the current to the battery would otherwise be excessive, power is dissipated in secondary loads (also referred to as *dump loads*, even though the energy is not actually wasted). This approach ensures that wind turbines will never have to be shut down due to excess power production, and that every bit of available wind energy will be used in an economically valuable way, either saving diesel fuel or displacing heating fuel. Remotely controlled electric boilers have been installed in the village school and the waste heat loop of the diesel plant, which is used to heat the plant itself and the diesel engines when they are not running.

2.6 System Controller

One of the principal technical objectives in this project is to develop a system that is as reliable and robust as possible consistent with the requirements of high wind penetration and maximum fuel savings. As with the rest of the system, the main control system is built up from proven industrial components using conservative design practices. The heart of the control system is a standard industrial PLC controller outfitted with the I/O modules necessary to monitor and control the system.

The control system is also equipped with a telephone interface to facilitate remote performance monitoring and fault diagnosis.

3 Requirements for Diesel Plant Automation

As stated above, a high-penetration wind-diesel system requires a fully automated diesel plant. Even though the generators may have been originally sized such that the village load could always be met by a single unit, the automated plant should allow unattended parallel operation of any combination of available units. In addition to ensuring stable load-sharing during diesel generator changeovers, this capability also allows the deferral of diesel capacity upgrades as the village load grows. The diesel generators must also behave stably and consistently when paralleled to other generating sources that are part of the system, such as the wind turbines and the energy storage power converter.

The ability to rapidly start and synchronize each diesel generator to the plant bus is another fundamental requirement of the automated plant. Diesel-off operation is the objective in a high-penetration system. In order to safely shut down all diesels, however, the supervisory controller must be able to reliably start and bring a diesel on-line on short notice. To minimize the amount of wind power margin required to run diesel-off and/or to gain the maximum benefit from the installed energy storage capacity, it is important to be able to start and synchronize the diesel engine in less than a minute, preferably much less.

In addition to these performance requirements, there are logistical issues involved in upgrading the plant. Ideally, the plant modifications should be done to minimize the amount of design, fabrication, assembly, wiring, etc., that must be performed on site. Such work is typically more difficult and more expensive to do in the field. Moreover, it is typically disruptive of plant operations, and to the extent that it causes prolonged power interruptions, it will dampen local enthusiasm for the project.

4 Diesel Plant Automation and Integration Issues Encountered in Wales

The start-up and debugging phases of the Wales project revealed a variety of ways in which the diesel plant, even after being retrofit with modern electronic diesel generator controls, failed to meet the requirements identified above. This section discusses the deficiencies in each major diesel plant subsystem.

4.1 Generators

During early parallel operation of the generators, we observed that whenever Unit 1 was paralleled with either of the other generators, the VAR load was not shared properly. Unit 1 acted as a reactive power sink. The other generator on-line, therefore not only had to meet the village VAR demand, it also had to meet the VAR demand of Unit 1. After determining that all of the voltage regulators and paralleling (i.e., VAR-sharing) modules were wired and functioning properly, we measured the harmonic content of the generator currents. We found a large third harmonic current circulating between the two paralleled generators, which is characteristic of parallel operation of generators of different winding pitch. We had the generator manufacturer trace the generator serial numbers and found that Unit 1 had a 7/9 pitch whereas Units 2 and 3 had 2/3 pitch generators. The plant had been functioning for years under manual control with this generator pitch mismatch. The circulating harmonic currents went unnoticed because parallel operation was limited to short periods of transitions between gensets and because stable long-term unattended load-sharing was not a requirement. Even under these circumstances, mismatched generators are undesirable because the circulating currents increase losses and cause an effective reduction of the individual generator ratings.

The generator pitch mismatch has major implications for the performance of the plant in automated operation. It is clear that the large harmonic currents are overwhelming the diesel VAR sharing controls. A similar situation is encountered when Unit 1 is paralleled with the rotary converter AC machine, which has a pitch of 2/3, matching Units 2 and 3. Although still somewhat speculative at this point, we believe that the harmonics are also interfering with the proper operation of the load-sharing modules, such that load-sharing is marginally unstable. Plans have been made to replace the Unit 1 generator with a 2/3 pitch generator. We are confident that this will completely solve the VAR-sharing problem and contribute greatly to load-sharing stability.

4.2 Generator Set Controls

The original Wales diesel controls did not contain the load-sharing or synchronizing controls necessary for automatic operation. Nor did they provide any means of automatically actuating the generator circuit breakers. Because they were designed for completely manual operation, there was no provision to place the controls in automatic mode. Early in the project, the decision was made to upgrade the existing control panels with the necessary additional controls rather than to replace them with new panels designed specifically to accommodate the wind-hybrid system.

The existing controls for all three generators were very densely packed in a cabinet more appropriately sized for one generator than for three. With some difficulty, the new suite of electronic controls (speed control, synchronizer, and load-sharing module) were added to this cabinet, but there was no room left for the additional relaying required to switch between manual and automatic operating modes, nor any space for terminal blocks for the interface to the new hybrid system control panel. Consequently, we had to design a Diesel Controls Interface Panel to fit in the narrow space between the existing generator control cabinet and the Wind-Diesel Control Panel. Several months were lost while waiting for this panel to be fabricated in Anchorage and then installed in the plant. Because of the large number of interconnections with existing equipment, the installation technician spent days working in electrically live cabinets next to operating diesel engines. This kind of work environment is conducive to wiring errors, which may only show up later and require extensive troubleshooting to locate. Those concerned with this installation agreed in retrospect that the more prudent and probably cost-effective approach would have been to replace the existing generator controls with preengineered and pretested automatic diesel control panels.

4.3 Engine Cooling System

Excess Back Pressure

The Wales diesel plant incorporated a jacket water waste heat recovery system (see Figure 2). The waste heat is used to keep the diesel plant buildings warm and to preheat off-line engines so that they can start rapidly and pick up load without a lengthy warm-up. The coolant discharge line from each engine is plumbed into a common discharge (“hot”) header, and the coolant intake line to each engine comes from a common intake (“cold”) header. The flow from the hot header passes through a water-to-water heat exchanger, which transfers heat from the engine coolant to the hydronic loop that heats the plant facilities. The flow may then either pass through some externally mounted air-cooled radiators to reject excess heat, or it may be returned directly to the engines via the cold header. A proportioning temperature control valve regulates the fraction of flow through the radiators and the fraction bypassing the radiators to regulate the temperature of the coolant returning to the engines.

The local dump load, an electric boiler equipped with its own circulation pump, was plumbed into this piping system as though it were a fourth diesel engine. In other words, it operates in parallel with the three engines, taking its flow from the intake header and discharging to the discharge header. An interesting phenomenon was observed during start-up testing of the hybrid system. Whenever multiple engines were operating simultaneously, or when the dump load circulation pump was operating in parallel with one or more diesel engines, there was a tendency for the engines to overheat. This was particularly true of engine #2, which was the smallest and had the weakest water pump. The effect of multiple pumps operating in parallel, all discharging into the same coolant loop, was to cause the pressure drop across that loop to rise above levels normally seen with a single engine operating. The water pumps in the individual engines were not always strong enough to ensure that there was sufficient flow through a particular engine. This problem had never previously manifested itself, because the manually operated plant only had one engine operating for any extended length of time, and this one engine’s water pump never had to compete with another pump trying to force flow through the same circuit.

We believe the basic layout of the cooling system to be acceptable, so the solution being pursued currently is to replace various components in the cooling loop with less restrictive versions to reduce the loop’s total resistance. This will ensure that any engine’s water pump is adequate to provide adequate coolant flow regardless of the operation of any other engine or the dump load pump.

Wasted Heat

Under manual diesel plant operation, with a diesel generator carrying the full village load, there is always more than enough diesel waste heat to keep the plant and the nonoperating engines warm. Consequently, some excess heat must always be dissipated by the radiators. With the wind system, however, this is not necessarily the case. In moderate winds, the wind turbines may be supplying most of the village load, and the diesel generator will be operating at low power, in which case there is little waste heat available. In higher winds, the diesels may be shut off completely, in which case there is no diesel waste heat. Because the plant and engines must nevertheless be kept warm, wind-generated electricity, via the plant dump load, must be used to make up for the loss of diesel waste heat. Whereas thermal energy conservation in the plant was previously not a concern, it now becomes very important.

In Wales, the diesel plant is an uninsulated and drafty building, and it requires a lot of energy to heat. This, combined with the fact that the temperature regulation valve that controls how much flow goes to the radiators was not working properly, meant that in early operation of the wind-diesel system, a lot of wind-generated electricity was being lost out the radiators. This meant that much more wind energy was being used to keep the plant warm than should have been required. Such heat loss causes a severe negative impact on the system economics, because wind energy used to keep the plant warm is not available to serve either the primary village electric load or the secondary load installed in the school heating system. Both of these loads are revenue generating, whereas the plant dump load is not.

Steps are currently being taken to improve the plant insulation and to ensure that the heat recovery system is working properly, such that no coolant flow goes to the radiators unless there is truly an excess of diesel waste heat.

4.4 Fuel Systems

Parallel operation of the diesel generators revealed problems with the existing fuel system as well. As with the cooling system, the fuel supply and return lines from the three engines share common supply and return headers coming from the day tank. Though still somewhat speculative, it appears that when multiple engines are running simultaneously, the combined fuel flow causes the back pressure in the fuel return lines to rise above an acceptable level for proper fuel injector operation. This high fuel back pressure may be contributing to poor engine speed control.

Another problem with the layout of the original fuel system is that the routing of the fuel lines between the day tank and the engines appears to contribute to the formation of air or vapor pockets in the lines when the engine is off. The current layout also may make it difficult to purge these air pockets from the piping. Again, while this behavior has not been positively confirmed, it appears that the fuel piping layout is causing fuel flow anomalies that only disappear after a fairly long warm-up time, making rapid synchronization difficult.

To address these problems, separate fuel supply and return lines for each engine will be run from the day tank, and these new lines will be routed in such a way as to minimize air/vapor entrapment.

4.5 Starter Battery Systems

When the Wales plant was a manual operation, diesel starting events were very infrequent. Since either of the larger engines was capable of meeting the peak village load, one of them was typically operated continuously for 10 days, at the end of which the load would be transferred to the other one and the first one serviced. The duty cycle on the engine starting batteries was therefore minimal. The battery charger did not need to be capable of rapid recharging. Because all starting operations were manual and therefore attended, if an engine was particularly difficult to start and required numerous retries, the operator could rest the battery as long as necessary between crank cycles.

With the automated system, however, optimal diesel dispatch requires more frequent diesel starts and stops. In addition, in the case of a hard-starting engine, it is important that the battery and charger be robust enough to start the engine within a programmed number of crank cycles to avoid an alarm condition and consequent loss of availability of that engine. In Wales, the existing battery charger was of an outdated design that did not have an automatic fast-charging mode. In certain situations, this limitation resulted in unreliable diesel starting. The battery charger is being replaced in conjunction with the other necessary diesel plant upgrades.

5 Project Planning and Implementation

The problems described in Section 4 of this paper were all discovered only after the diesel plant began to be operated as part of an automated hybrid system. That is because during the project development, our attention was focused on the hybrid system controls development and not on the detailed impact of the system on diesel plant operation. These particular problems would not all necessarily be present in another village power plant, nor are they the only problems that might occur. The main lesson to be learned from this experience is the importance of conducting a thorough assessment of the existing diesel plant early in the planning stages of a wind hybrid retrofit project.

The first step in this assessment is to identify any features of the existing plant design that could *potentially* interfere with fully automatic operation of the plant. It will not always be possible to predict the exact behavior of individual diesel plant subsystems in operating modes that have never been experienced. Therefore, it is prudent to note all potential problems as well as obvious ones. The following are questions that may help to identify problem areas:

- What capabilities do the current diesel controls lack that are necessary for automatic operation (e.g., auto synchronization, load-sharing, VAR-sharing, remote breaker closure, automatic feeder control, etc.)

- Are any of the diesel piping systems (fuel, lubricating oil, coolant, exhaust, etc.) designed in such a way that the performance of one diesel is influenced by the simultaneous operation of another?

- Are the generators matched in pitch? If not, have steps been taken to eliminate or mitigate circulating harmonic currents?

- Does the diesel plant rely in any way on having excess waste heat available?

- Do the engines have similar dynamic response? (If not, it will be difficult to achieve good load-sharing performance.)

- Are there any actions the operators currently perform (consciously or not) that tend to compensate for inadequacies in any of the diesel plant systems?

- What alarm or fault conditions currently occur in the diesel plant? What is their impact on manual plant operation? What would their impact be on automatic plant operation?

- Are there any factors present that would compromise the performance of a waste heat recovery system?

The second step in the assessment is to determine what diesel plant modifications would be required to rectify the problems or deficiencies identified. There may be multiple engineering solutions to any given problem. All possible approaches should be identified.

Lastly, one must determine the true cost of performing the upgrades and modifications to the existing plant. To do this, one must consider not only the costs of parts and labor, but various other costs and risks as well, including:

- the cost of doing engineering designs that may only apply to this one installation
- the difficulty of doing fabrication and installation work in the field
- the risk of design and installation error
- the loss of revenue and customer good will associated with outages necessitated by diesel plant rework
- the risk of delays to the project if the plant requires extensive rework

In many cases, these costs and risks may be relatively minor. Even when they are significant, they can often be reduced by good project planning. In some cases, however, it will be more cost-effective to replace major subsystems than to upgrade them. Frequently, for example, it will be more cost-effective to scrap the existing generator controls and start fresh with new automation-ready diesel control panels. In cases of very old plants or plants that have been incrementally expanded over the years with lots of dissimilar components and/or with poor documentation, the best approach may be to replace the entire plant with a new one optimized for the wind hybrid system. The gains in system lifetime, speed of installation, ease of maintenance, and overall reliability may more than make up for the increased capital cost.

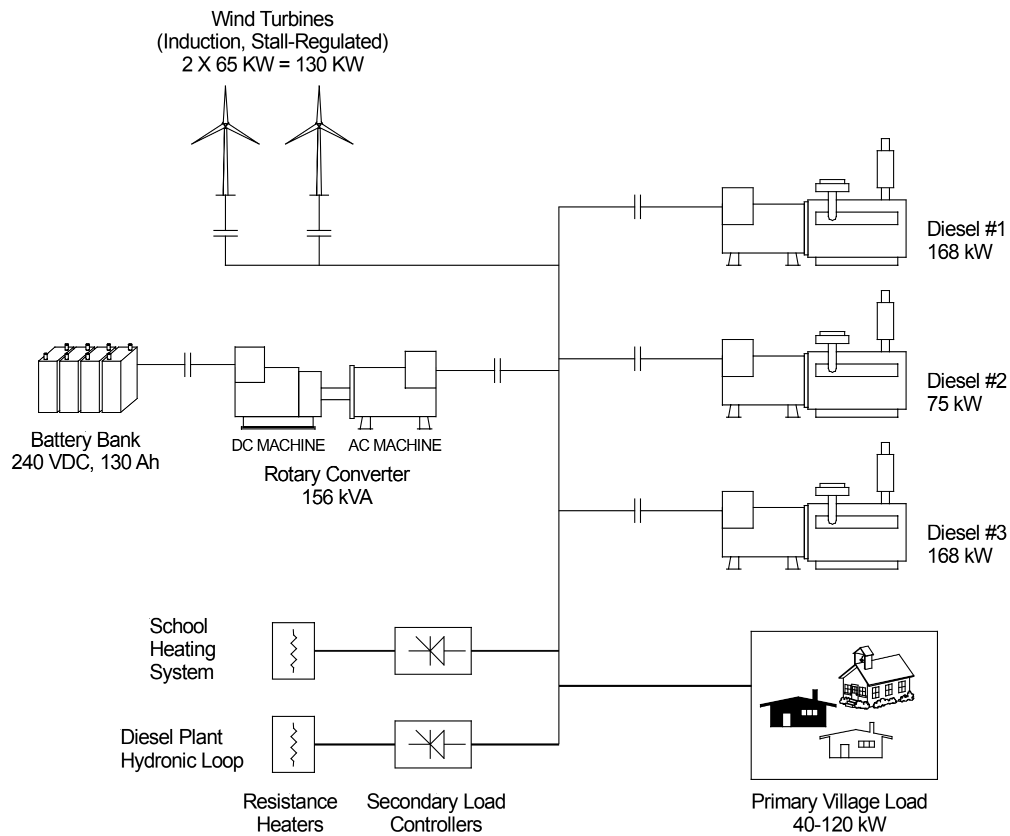

Figure 1 Wales High-Penetration Wind-Diesel Hybrid Power System

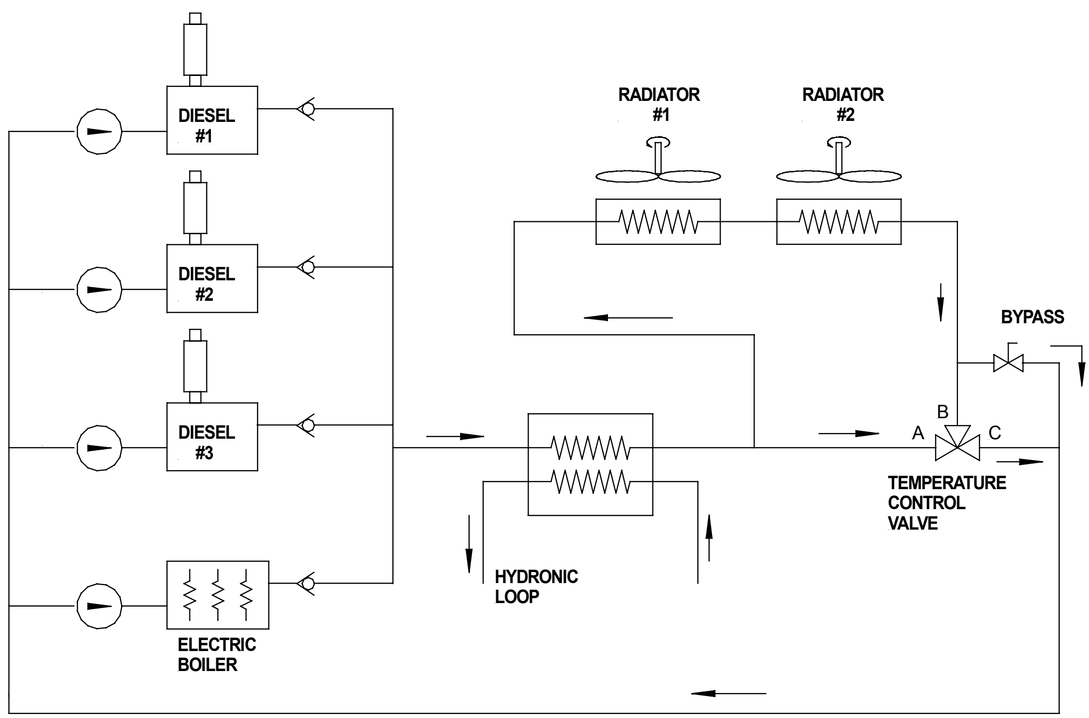

Figure 2 Wales Diesel Plant Cooling and Heat Recovery System Layout

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE August 2001	3. REPORT TYPE AND DATES COVERED Conference paper

4. TITLE AND SUBTITLE
Preparing an Existing Diesel Power Plant for a Wind Hybrid Retrofit: Lessons Learned in the Wales, Alaska, Wind-Diesel Hybrid Power Project

5. FUNDING NUMBERS
WER11720

6. AUTHOR(S)
Stephen Drouilhet

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NREL/CP-500-30586

11. SUPPLEMENTARY NOTES

NREL Technical Monitor:

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This paper describes the wind-diesel hybrid power project, a technology demonstration project conducted by the National Renewable Energy Laboratory, Kotzebue Electric Association, the Alaska Village Electric Cooperative and the Alaska Energy Authority in Wales, Alaska. It discusses each of the relevant plant design considerations in detail, in hopes that system integrators and project planners that read the report will realize the importance of giving proper attention to diesel plant preparation (or replacement), and future wind-diesel systems will be installed and commissioned more quickly and cost effectively.

14. SUBJECT TERMS
wind energy hybrid systems; Wales; Alaska; Kotzebue

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102